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Multicriteria Environmental Sensitivity Evaluation of the Urban Road Network Using Analytic Hierarchy Process and Fuzzy Compositional Approach

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Abstract:

Multicriteria environmental impact evaluation is an important process which can lead to the better understanding of complex road/environment interactions on an urban road network The Analytic Hierarchy Process (AHP), using both the principle of hierarchic composition (compensatory) methods and the fuzzy compositional evaluation (non-compensatory) method, was applied to determine the combined environmental sensitivity characteristics (based on the Environmental Sensitivity Methodology (ESM)) of the road network of central Geelong It was found that AHP can operate as a powerful tool for the multicriteria decision making environment The compensatory method performed better than the non-compensatory method in differentiating road links according to their composite environmental sensitivity characteristics. However, the latter can also be used as a more conservative multicriteria decision making tool

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Introduction

Residents and pedestrians who live or perform their activities adjacent to main roads in urban area have often suffered from the pedestrian danger, amenity degradation and adverse environmental impacts caused by road traffic. These people are gradually becoming more aware of these effects. The adverse impacts includes air pollution, difficulty of access, noise and vibration, pedestrian crossing delays, pedestrian safety, severance, visual intrusion, fear and intimidation (Singleton and Twiney, 1985; May, 1988). The estimation and assessment of such impacts is difficult and complicated. Local governments and other agencies have tried to alleviate these problems by adopting the concept of the functional road hierarchy classification and then applying the different traffic management schemes accordingly. However, the vital prerequisite to the success of the established functional road hierarchy classification and therefore the implemented traffic management schemes is the understanding of complex interactions between road traffic and its abutting land uses.

In Australia, several concepts such as environmental capacity (EC) (Holdsworth and Singleton, 1979 and 1980), amenity sensitivity (AS) (Loder and Bayly, 1980), and environmental sensitivity method (ESM) (Singleton and Twiney, 1985) were adopted to capture the intensity of road/environment interactions. The first two methods appear to have some limitations and shortcomings (Singleton and Twiney, 1985; Klungboonkrong and Taylor, 1996). Therefore, ESM was introduced to determine the degree of the road/environment interactions, namely the environmental sensitivity (ES) for several criteria at local level, identify problem locations in the concerned road network, specify the possible causes (criteria) of each problem location and lastly indicate the likely contributing factors to each cause (Singleton and Twiney, 1985; Klungboonkrong and Taylor, 1996). ESM has been widely applied as an important input for various road hierarchy classification studies and an indication of environmental conflict locations and their possible causes in Australia (Ove Arup Transportation Planning, 1983 and 1989; Singleton and Twiney, 1985).

The final outcomes derived from ESM analysis are the link's ES indices (low, medium and high) for each selected criterion. In practice, it is essential to combine these separate ES indices estimated for different criteria of a given link in order to assess and compare the composite ES indices (CESIs) of all different links in a road network. Such indices can be utilised to uncover the ranking order among different road links according to the degree of the CESIs of each link. The resultant ranking order is of particular importance in prioritising the special investigation and allocating limited budget for the implementation of suitable traffic management schemes on different links in a road network. The well known multiattribute decision making (MADM) approach, namely Analytic Hierarchy Process (AHP) is used to combine both tangible and intangible criteria and to recognise differences in the relative importance of these criteria in different land use types (Saaty, 1980; Vargas, 1990; Zahedi, 1986).

This paper is organised to present the following topics: (i) introduction to a multiple attribute decision making approach; (ii) Analytic Hierarchy Process methodology; (iii)

Fuzzy Compositional Evaluation method; (iv) the Geelong case study; (v) the results' interpretation and comparison; and lastly (vi) conclusion.

Introduction to multiple attribute decision making (MADM)

Multiple criteria decision making (MCDM) processes can be divided into two main types: multiple attribute decision making (MADM) and multiple objective decision making (MODM) (Jankowski, 1995). MADM deals with a selection of the best choice from a small or moderate size of set of discrete alternatives based on the decision criteria and criterion priorities, while MODM involves a searching for optimal solution in a feasible solution space confined by a set of constrains. The nature of the decision making problem presented in this paper is well fitted to the MADM approach. Therefore, this paper deals only with MADM. MADM can also be separated into two classes: compensatory and non-compensatory. The compensatory approach assumes that the preference score of any alternative derived on single or multiple criteria can be traded off by those of the same alternative on other criteria. In contrast, the non-compensatory approach does not allow for such compensation.

Several techniques were established to handle MADM problems. These techniques include simple additive weight (SAW), concordance analysis, ideal point analysis, AHP and others (Hwang and Yoon, 1981). One of the most popular approaches is AHP. The AHP is becoming more popular over other methods in decision making process, because of its simplicity, its promising accuracy, its theoretical robustness, its ability to handle both intangible and tangible criteria and importantly, its capability to directly measure the inconsistency of respondent's judgments (Saaty, 1990a and Vargas, 1990). Therefore, AHP is used in this study. This paper deals with both the compensatory approach (AHP using the Principle of Hierarchic Composition) and non-compensatory approach (AHP using the Fuzzy Compositional Evaluation approach).

Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a mathematical method used to determine the priorities of different decision alternatives via pairwise comparisons of decision elements with respect to a common criterion. The AHP is based on the empirical findings that the human mind has certain difficulties in dealing with many decision criteria or alternatives simultaneously. However, humans are capable of well evaluating only two elements at the time. Hence, the pairwise comparison approach coupled with a ratio scaling method has been used to uncover the relative importance among all decision criteria in multiple attribute decision-making environment. The following discussion is mainly based on the context of the Geelong case study which will be described in detail later. The AHP is based on three principles as illustrated in Figure 1 and discussed below (Saaty, 1980; Zahedi, 1986):

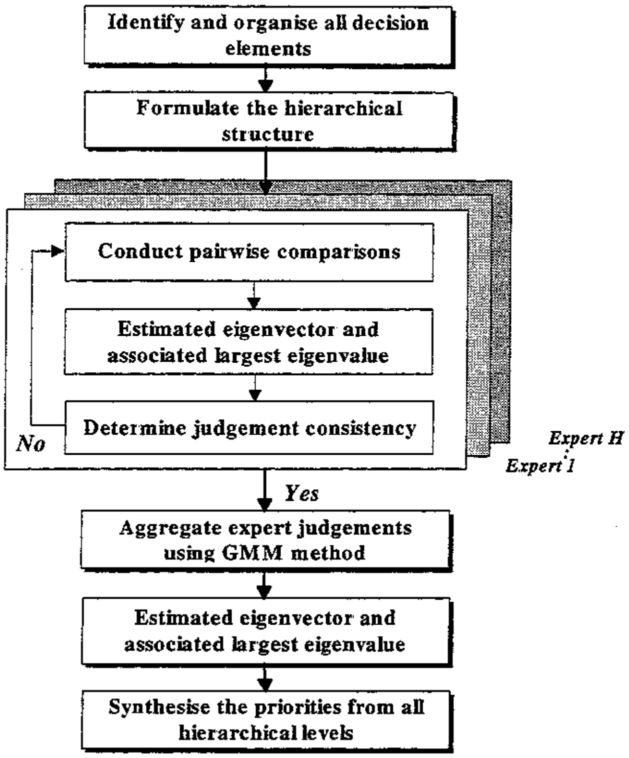

Figure 1: The AHP flowchart diagram

Decomposition: A hierarchical structure is established by decomposing the complex problem into a hierarchy of interrelated decision elements. This structure is the key to interrelate and chain all decision elements of the hierarchy from the top level down to the bottom. The global objective (estimation of CESIs of all road links) is placed at the top of the hierarchical structure. The lowest level of the hierarchy structure consists of more detailed elements (ES indices (eg low, medium and high)) which interrelate to the parent elements (environmental criteria) in the next higher level. Typically, the alternatives are contained in the lowest level of the hierarchy. However, this study used the AHP absolute mode approach. Therefore, all road links (alternatives) will not be pairwise-compared directly, but each link was assigned its ES scores according to the knowledge contained in the experts' memory (using the ESM concept). The hierarchical structure for this study is presented in Figure 2.

Prioritisation: Once the hierarchical structure was established, the relative importance (weights) of all decision elements is explicitly captured and revealed through ratio scale approach. Pairwise comparisons of these elements within the same hierarchical level with respect to the parent elements in the next higher level are established. The input data can be achieved from individual interviews of several experts. The typical question to each expert is that "Which one of the pair is more important with respect to an parent element in the next higher level? and How much is the intensity?" The numerical scale and its definition used in the pairwise comparisons are given in Table 1.

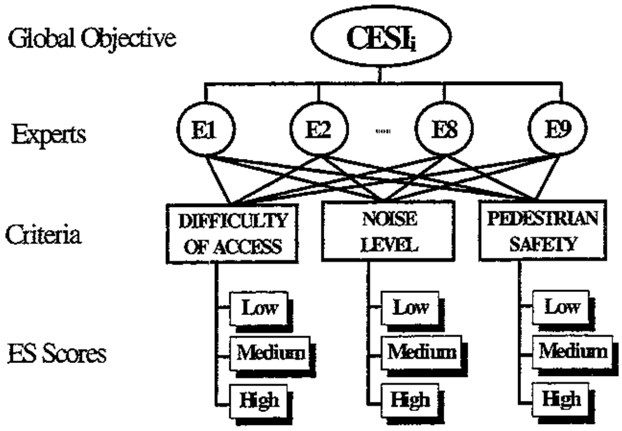

Figure 2: A hierarchical structure of the CESI estimation for each land use type

Table 1: Scales of relative importance

Intensity of Importance	Definition
1	Equal importance
3	Weak importance of one over the other
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgements

Source: (Adapted from Saaty (1994), p. 26)

In this study, nine experts were interviewed to provide their judgements regarding the relative weights of different decision elements in the same hierarchical level. Several sets of pairwise comparison matrices of elements in the same level which attribute to accomplishing the goals of the parent element in the next higher level are finally obtained as shown in equation 1. For each expert, the derived pairwise comparisons of relative importance, $a_{ij} = w_i/w_j$, for all decision elements and their reciprocals, $a_{ji} = 1/a_{ij}$, are inserted into a reciprocal square matrix $A = \{a_{ij}\}$ as shown in equation 1.

$$A = \begin{bmatrix} 1 & w_1/w_2 & \ldots & w_1/w_n \\ w_2/w_1 & 1 & \ldots & w_2/w_n \\ \vdots & \vdots & ::: & \vdots \\ w_n/w_1 & w_n/w_2 & \ldots & 1 \end{bmatrix} \qquad (1)$$

In each square matrix, all diagonal elements are equal to one and the lower triangle elements of the matrix are always the reciprocal of the upper triangle elements. Therefore, pairwise comparisons are conducted for only half of the matrix elements ($N_k(N_k-1)/2$), excluding diagonal elements, where N_k is the number of decision elements to be compared in hierarchical level k (Zahedi, 1986). It should be noted that when N_k is very high, the pairwise comparisons to be conducted are extensive. This is one of the critical shortcomings of the typical AHP. The analytical solution of equation 2 then provides the relative weights for each decision element. According to the eigenvalue method (Saaty, 1980), the normalised right eigenvector $(W = [w_1, w_2, \ldots, w_n]^T)$ associated with the largest eigenvalue (λ_{max}) of the square matrix A provides the weighting values for all decision elements.

$$AW = \lambda_{max} W \qquad (2)$$

A Consistency Index (CI) is used to measure the degree of inconsistency in the square matrix A (where, $CI = (\lambda_{max} - n)/(n-1)$). Saaty (1980) compared the estimated CI with the same index derived from a randomly generated square matrix, called the Random Consistency Index (RCI) as shown in Table 2. The ratio of CI to RCI for the same order matrix is called the Consistency Ratio (CR). The judgmental consistency of each expert will be determined. Generally, CR of 0.10 or less is considered acceptable, otherwise the matrix A will be revised to improve the judgmental consistency.

Table 2: The random consistency index (RCI)

n	1	2	3	4	5	6	7	8	9
RCI	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45

Source: (Adapted from Saaty (1994), p. 42)

The Geometric Mean Method (GMM) (Saaty, 1989), as shown in equation 3, was employed to aggregate different judgments from several experts. It should be noted that only consistent expert judgements would be included in this step. According to a GMM method, the geometric means (a_{ij}^{gp}) of the paired comparisons conducted by each expert (a_{ij}^{h}) are inserted into the group pairwise comparison matrix which is similar to the reciprocal square matrix A mentioned previously and then the eigenvalue method is used to estimate the group relative weights of all experts.

$$a_{ij}^{gp} = (a_{ij}^{1} \cdot a_{ij}^{2} \cdot \Lambda \cdot a_{ij}^{h} \cdot \Lambda \cdot a_{ij}^{H})^{1/H} = (\prod_{h=1}^{H} a_{ij}^{h})^{1/H} \qquad (3)$$

where, $a_{ij}^{h} = (w_i / w_j)$ is an element of the square matrix A of a decision maker h. H is the total number of human experts. In addition, AHP can also determine the consistency of group judgements and the relative departure of an individual judgement from the group preference (Saaty, 1989). However, in this study, it is assumed that the consensus among different individuals can be mathematically achieved by applying the GMM approach.

Synthesis: The weighting values for all decision elements (eg alternatives) at the lowest hierarchical level are derived from the "Principle of Hierarchic Composition" as shown in equation 4.

$$\mu_i = \sum_{j=1}^{n} \mu_j \mu_{ij} \qquad (4)$$

where, μ_i is a global weights of decision element i; μ_j is a local weight of a criterion j: and μ_{ij} is a local weight of an assigned ES index of link i for criterion j. Equation 4 means that the global relative weight of any decision element i can be obtained from the summation of multiplication of the relative weights of criteria and those of the corresponding ES indices of link i across all criteria. This can be considered as a compensatory MADM approach.

The Fuzzy Compositional Method

There may be some difficulties in interpreting the results derived from the typical AHP (AHP with principle of hierarchic composition) approach. This is because such an approach allows for a high degree of compensatory justification among different criteria. For example, a high ES index for a lower relative weight criterion can possibly be compensated by a low ES index for a higher relative weight criterion. This may result in misleading interpretation of the derived outcomes (Klungboonkrong and Taylor, 1996). Therefore, the fuzzy compositional AHP (AHP with the fuzzy compositional evaluation method) has been applied to investigate and compare the obtained results with those of the typical AHP. Prior to discussing the fuzzy compositional evaluation method, the basic concept of fuzzy set theory is introduced and described.

The fundamental basis of fuzzy set theory

Zadeh (1965) introduced the fuzzy set concept as a collection of elements and its degree of belonging, called grade of membership. This can be done by adopting the concept of a membership function to assign a number ranging from zero (absolutely not belonging) to unit (fully belonging) according to the degree (grade) of belonging to each element of a universe of discourse. Suppose that $X = \{x\}$ is a universe of discourse. Then a fuzzy set (subset) A in X is defined as a set of ordered pairs $\{(x, \mu_A(x))\}$, where $x \in X$ and $\mu_A : X$

→ [0, 1] is the membership function of A; $\mu_A(x) \in [0, 1]$ is the grade of membership of x in A (Fedrizzi and Kacprzyk, 1995). The fuzzy subset A of X is expressed in equation 5 for an infinite universe of discourse

$$A = \int_X \mu_A(x)/x \tag{5}$$

where $\mu_A(x)/x$, called a singleton, is a pair of grade of membership and element of a fuzzy set A and '$\int$' signs mean a union operation in the ordinary set theory.

The fuzzy relation and fuzzy compositional evaluation

$X = \{x_1, x_2, \ldots, x_n\}$ is defined as a criterion set containing all selected criteria to be determined. $Y = \{y_1, y_2, \ldots, y_m\}$ is defined as an evaluation set consisting of all decision elements (road links) to be evaluated with respect to each criterion in X. The fuzzy relation, $\boldsymbol{R}$, from X to Y, called fuzzy evaluation matrix, is a fuzzy set in the Cartesian product of X and Y ($X \times Y = \{(x, y) \mid x \in X, y \in Y\}$. The fuzzy relation, $\boldsymbol{R}$, is characterised by membership function μ_R (x, y) and is denoted as $\boldsymbol{R} = \boldsymbol{X} \times \boldsymbol{Y} = \{\mu_R(x, y)/(x, y) \mid x \in X \textit{ and } y \in Y\}$ and shown in equation 6 (Grivas and Shen, 1995). Therefore,

$$\boldsymbol{R} = \begin{bmatrix} \mu_R(x_1, y_1) & \mu_R(x_1, y_2) & \Lambda & \mu_R(x_1, y_m) \\ \mu_R(x_2, y_1) & \mu_R(x_2, y_2) & \Lambda & \mu_R(x_2, y_m) \\ \vdots & \vdots & ::: & \vdots \\ \mu_R(x_n, y_1) & \mu_R(x_n, y_2) & \Lambda & \mu_R(x_n, y_m) \end{bmatrix} \tag{6}$$

where $\mu_R(x_n, y_m)$ is a membership function of a fuzzy relation $\boldsymbol{R}$ from a criterion, x_n in a criterion set $\mathbf{X}$ to a evaluated element, y_m in a evaluation set Y. $\boldsymbol{A}$ is a fuzzy set in set $\boldsymbol{X}$ and characterised by membership function μ_A (x) and is denoted as $A = \{\mu_A(x)/x \mid x \in X\}$. $\boldsymbol{A}$ is called weight vector of $\boldsymbol{X}$. μ_A (x_i) is a fuzzy weighting value of criterion x_i in X. Therefore,

$$A = \{\mu_A(x_1),\ \mu_A(x_2),\ \Lambda\ ,\ \mu_A(x_n)\} \tag{7}$$

In this study, the max-min composition is used because it has been well researched and widely used in various applications (Lin and Shieh, 1995; Zimmermann, 1996). The fuzzy relational composition, $\boldsymbol{B}$, of a fuzzy set A and a fuzzy relation $\boldsymbol{R}$ is denoted as follows:

$$\boldsymbol{B} = \boldsymbol{A} \circ \boldsymbol{R} \tag{8}$$

The membership function of $\boldsymbol{B}$ is denoted as

$$\mu_B(y)=\mu_{A\circ R}(y)=\bigvee_{x\in X}\{\mu_A(x)\wedge\mu_R(x,y)\}=\max_{x\in X}\min\left[\mu_A(x),\ \mu_R(x,y)\right] \qquad (9)$$

Equation 9 means that for each criterion (x), the grade of membership (relative weight) of that specific criterion are compared to the grade of membership of the derived ES index of a link (y) for the same criterion. The minimum of these two values is kept and then compared with the similar values for the remaining criteria. The maximum of all minimum values for every criterion is used to represent the final fuzzy compositional evaluation (CESI value). Therefore, the CESI value of each decision element is solely determined according to the most critical criterion. This method is therefore the non-compensatory approach.

In practice, the main problem in applying this method is the derivations of the suitable weight vector (***A***) for several criteria and the appropriate fuzzy evaluation matrix (***R***) of all decision elements (Lin and Shieh, 1995). In this study, the ESM concept is used to provide the appropriate ES indices for each road link given required road physical and land use characteristics as presented in Ove Arup transportation Planning (1989). AHP is also applied to transfer and aggregate the relevant knowledge (in terms of the relative weights of all selected criteria for each land use type and the relative weights of ES indices for each criterion) from several human experts. As a result of the comprehensive empirical analysis and theoretical support, Kumar *et al* (1996) recently found that the use of AHP to estimate fuzzy membership values in a fuzzy set is justified.

The Geelong case study

The City of Geelong, Victoria, Australia was adopted as a case study area. Its road network is basically a grid system as illustrated in Figure 3. The focus of the case study was to determine the ES of all roads which reflects the perspective of the residents and pedestrians living or performing their activities within abutting land uses. The main roads, which serve both traffic mobility and frontage related activity functions (eg access, shopping, etc) were the main subject of this study. As illustrated in Figure 3, several main roads in Geelong were selected and these roads were divided into 66 homogeneous links according to the criteria suggested by Singleton and Twiney (1985) and indicated in Ove Arup Transportation Planning (1989). The physical and land use characteristics along each of these divided links were gathered from available data obtained from Ove Arup Transportation Planning (1989), the raster image of aerial photograph of the central Geelong area and others. These include: (i) physical characteristics of the roads; (ii) pedestrian facilities; (iii) nature of parking restrictions; (iv) type and practicality of land use access; (v) adjacent land use categories; (vi) typical building setback from the property line; and (vii) building facade orientation. The database has been established within a geographical information system (GIS) environment, namely MapInfo. The analysis results will also be illustrated by using MapInfo.

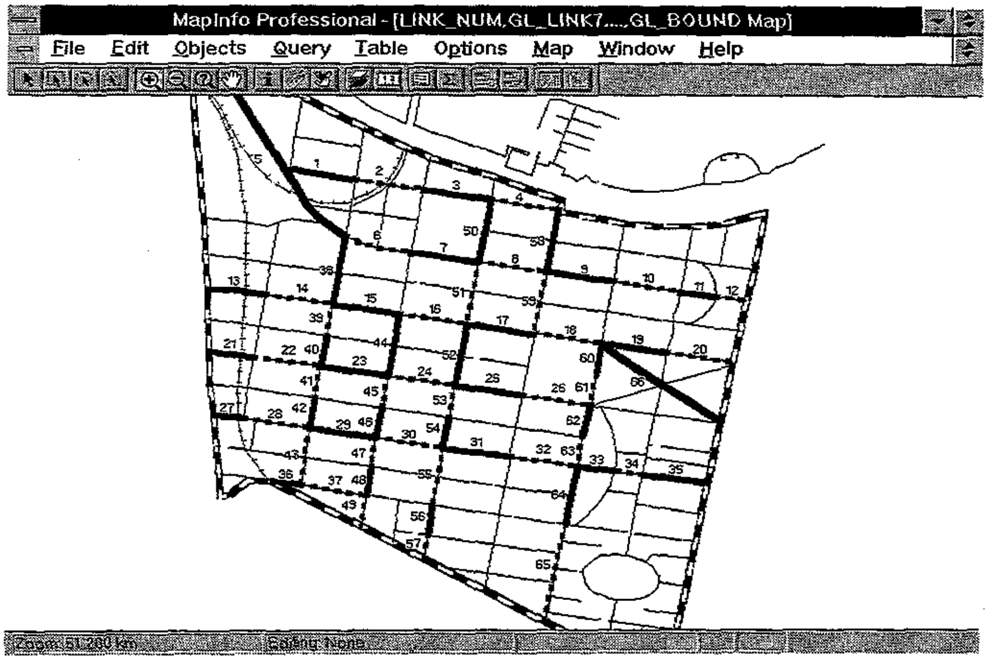

Figure 3: The road network of central Geelong

Previous research has indicated that residents living along busy roads are most concerned about four aspects, namely air pollution, noise, pedestrian crossing delay and pedestrian safety (Holdsworth and Singleton, 1979; Hollingworth, 1982; May, 1988). As a result of public consultation presented in Ove Arup Transportation Planning (1989), three criteria selected for the Geelong case study were difficulty of access, noise level and pedestrian safety. Nine selected experts (eg local government officers, urban planners, traffic engineers, academic professor, etc) were directly interviewed. Based on their experiences and expertise, these experts served the community as the 'measuring instrument' in determining the relative weights of these criteria for each land use type and those of all ES indices for each criterion. All land use types were classified as suggested by Singleton and Twiney (1985) and indicated in Table 5.

The AHP methodology

The decision problem is formulated as the hierarchical structure and the relationship among these decision elements contained in each hierarchical level is illustrated in Figure 2. The AHP structure consists of four hierarchy levels as follows: (i) the global objective level: an evaluation of the CESIs of all links in the road network; (ii) the expert levels: an indication of group decision making problem: (iii) the environmental criteria: difficulty of access, noise level and pedestrian safety: (iv) the ES indices: low, medium and high for each criterion. This study assumed that the relative weights (numerical meanings) of these identical indices may be different for different criteria. The last (fifth) level, namely the evaluated road links, was not indicated in the AHP hierarchy structure. This is because such links were not directly pairwise-compared with respect to each criterion, but rated as low, medium or high according to a standard knowledge in memory that human experts have developed through the past experiences. Given the required data of road physical and land use characteristics of any road links, the concept of ESM was applied to determine the appropriate ES indices for each criterion. This process, called the '*absolute mode*' method, is very useful and practical particularly when dealing with numerous alternatives.

Each example of the pairwise comparison matrices and the estimated relative weights of the three selected criteria for each land use type and those of all ES indices for each criterion are shown in Table 3 and 4, respectively. The estimated CR values for these two matrices were less than 0.10, these resultant pairwise comparisons were considered consistent. The GMM was then applied to aggregate different judgments of the nine experts and the estimated group relative weights of three selected criteria for each land use type and all ES indices for each criterion were finally achieved as presented in Table 5 and 6, respectively. The derived group preferences were tested and found to be consistent.

Table 3: Pairwise comparisons of all criteria for land use type II by expert 3

Environmental Criteria	(1)	(2)	(3)	Weights
(1) Difficulty of Access	1	1.5	2/3	0.3189
(2) Noise Level	1/1.5	1	1/2	0.2211
(3) Pedestrian Safety	3/2	2	1	0.4600

$\lambda_{max} = 3.002$, $CI = 0.001$, and $CR = 0.001$

Table 4: Pairwise comparisons of all ES Indices for noise level criterion by expert 3

ES Indices	(1)	(2)	(3)	Weights
(1) Low	1	1/4	1/8	0.0702
(2) Medium	4	1	1/4	0.2227
(3) High	8	4	1	0.7071

$\lambda_{max} = 3.054$, $CI = 0.027$, and $CR = 0.052$

Table 5: Group relative weights of all criteria by land use types

Land Use Types	Environmental Criteria		
	Difficulty of Access	Noise Level	Pedestrian Safety
(I) Residential/School/Hospital	0.2755	0.3155	0.4090
(II) Retail/Commercial/Office/Park	0.3477	0.1886	0.4636
(III) Industrial/Railway	0.6067	0.1248	0.2685

Table 6: Group relative weights of all ES indices by criteria

Environmental Criteria	ES Indices		
	Low	Medium	High
(1) Difficulty of Access	0.0976	0.2692	0.6332
(2) Noise Level	0.0856	0.2495	0.6649
(3) Pedestrian Safety	0.0853	0.2644	0.6503

It should be noted that as shown in Table 5, the relative weights among those three selected criteria clearly vary with land use types. For land use type I, pedestrian safety has the greatest relative weight and is followed by noise level and difficulty of access, respectively. However, relative weight values of these three criteria are only slightly different from each other. For land use type II, relative weight of pedestrian safety is still the maximum one and is followed by those of difficulty of access and noise level, respectively. It should be noted that the relative weight of difficulty of access is much greater than that of noise level. For land use type III, in contrast to land use type I and II, difficulty of access becomes the most important criterion and is followed by pedestrian safety and noise level, respectively. It should be pointed out that the relative weights of difficulty of access is considerably greater than those of the other two criteria.

As indicated in Table 6, the relative weights (numerical values) of all ES indices for the three criteria are almost identical. The relative weights of '*low*' and '*medium*' are significantly lower than that of '*high*'. However, the numerical values of '*medium*' is closer to that of '*low*' than that of '*high*'. This implies that for the purpose of identifying problem locations, group judgements of several experts have assigned the considerably high relative importance to '*high*' than those of '*low*' and '*medium*' and the derived relationship among these ES indices is non-linear.

Interpretation

As an illustration, all ES indices of all links for each of pedestrian safety are illustrated in Figure 4. For the typical AHP, the CESI values can be calculated from the summation of the multiplication of the links' relative weights of the ES indices for difficulty of access, noise level and pedestrian safety with appropriate relative weights of these three criteria corresponding to the link's land use type. It should be noted that the estimated weights of all ES indices for each criterion were normalised by dividing with the maximum weight of these estimated ES indices prior to performing the multiplication. For example, link 25 lying in land use type I along Myers Street was assigned the '*medium*', '*high*' and '*high*' ES indices for difficulty of access, noise level and pedestrian safety, respectively. According to the relative weights estimated for the three criteria in land use type I and those for ES indices of each ES criterion, the CESI of link 25 is 0.842 ((0.276×0.425)+(0.316×1.000)+(0.409×1.000)). All CESI values estimated for every link in the Geelong road network were arbitrarily grouped into six intervals and illustrated in Figure 5. The estimated CESIs can be used to assess the likely composite ES effects of different criteria for each link. Such indices can be utilised to identify problem locations and reveal the ranking order corresponding to the degree of the composite ES of each link. As illustrated in Figure 5, eight links (link number: 21, 25, 26, 27, 28, 32, 43, 49) having the same CESI value of 0.842, fall within the highest CESI interval (CESI is greater than 0.800) and therefore, show an indication of environmental problem. In addition, the numerical composition of CESI values can also be used to indicate the possible causes of the problem for each link. For example, for link 25, the descending rank of likely causes (criteria) of the environmental problem on this link are: pedestrian safety (0.409 = (0.409 ×1.0)); noise level (0.316 = (0.316×1.0)); and difficulty of access (0.117 = (0.276× 0.425)), respectively.

For the fuzzy compositional AHP, the CESI values can be estimated from the fuzzy compositional evaluation. The links' relative weights of the ES indices for difficulty of access, noise level and pedestrian safety are directly compared to the appropriate relative weights of these three criteria corresponding to the link's land use type. Therefore, those relative weights of each criterion for each land use type and those of all ES indices for each criterion were normalised by dividing with the maximum weights prior to conducting fuzzy compositional reasoning. For example, as shown in Figure 6, the CESI of link 25 is 1.000 (max [min (0.674, 0.425), min (0.771, 1.000), min (1.000, 1.000)] ≡ max [0.425, 0.771, 1.000]). The CESI value for all eight links mentioned previously are identically equal to 1.000 (the maximum CESI value) and clearly indicate environmental problem. The possible cause of the environmental problem of these links is pedestrian safety. This approach can identify only the most critical cause (criterion) for each link. The similar interpretation for both the typical AHP and the fuzzy compositional AHP approaches can be applied to all of the remaining links.

Comparisons between the compensatory and non-compensatory approaches

The estimated CESI values of all links using the typical AHP (compensatory) method and the fuzzy compositional AHP (non-compensatory) method were illustrated in Figure 6. Given the fact that the compensatory MADM approach may generate misleading outcomes and interpretation, Figure 6 clearly illustrates that the typical AHP performs better in terms of differentiation capability than the fuzzy compositional AHP. While the typical AHP takes all criteria into account, the fuzzy compositional AHP will take only the most critical criterion into consideration and eliminate other remaining criteria. Therefore, the later can be determined as a conservative approach. However, as shown in Figure 6, the fuzzy compositional AHP can capture a number of very high (eg link number: 21, 25, 26, 27, 28, 32, 43, 49, and others) and very low (eg link number: 1, 4, 7, 19, 47, 48, 51, 53 and others) CESI values which well match to the CESI values estimated by the typical AHP.

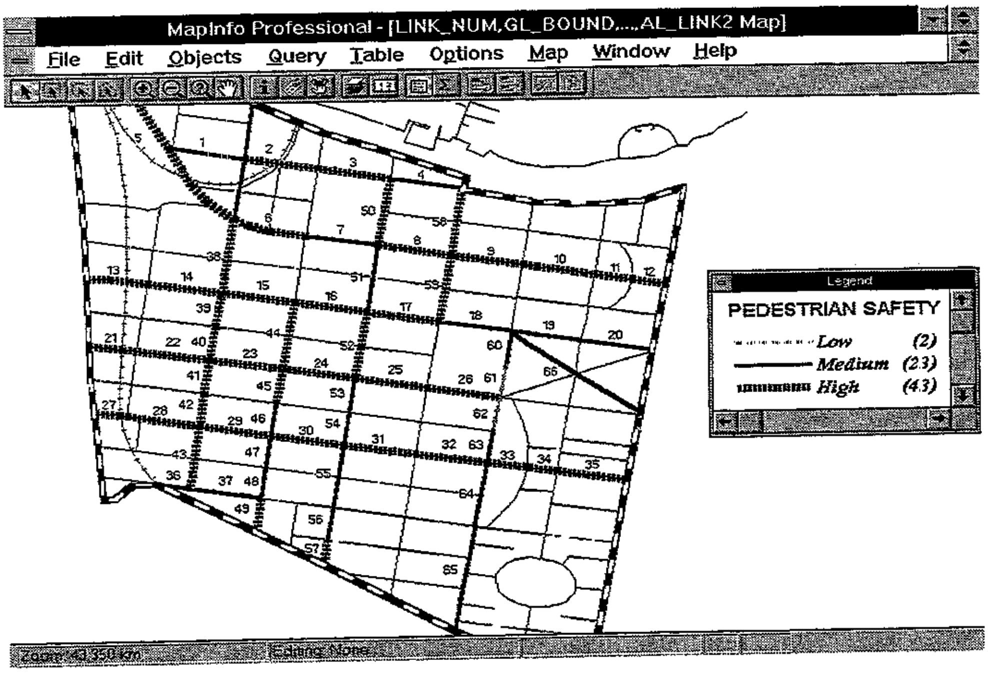

Figure 4: The ES indices for pedestrian safety

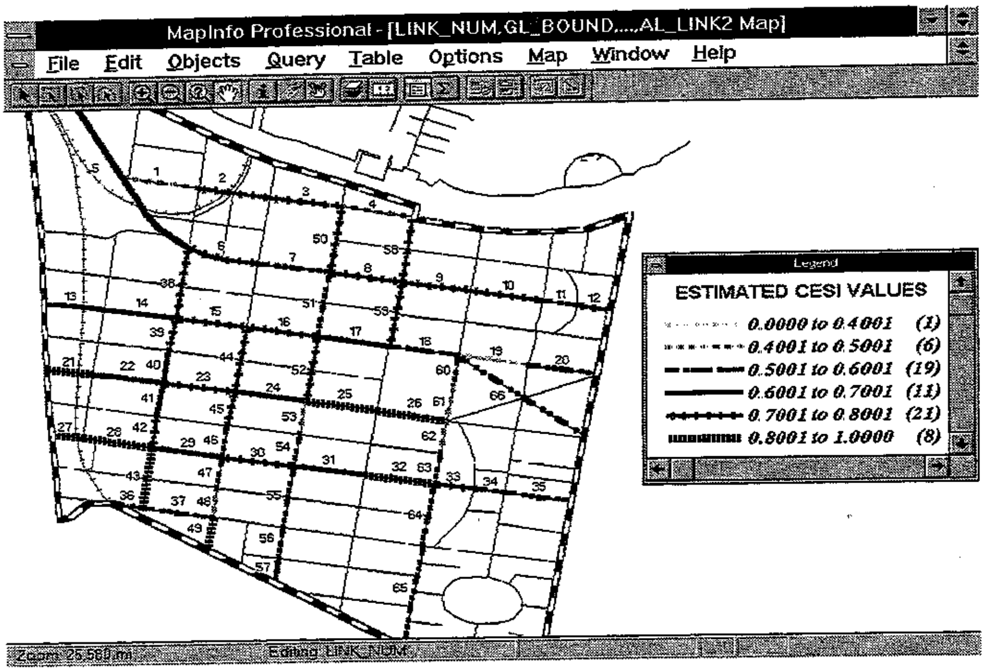

Figure 5: The estimated CESI values for all links

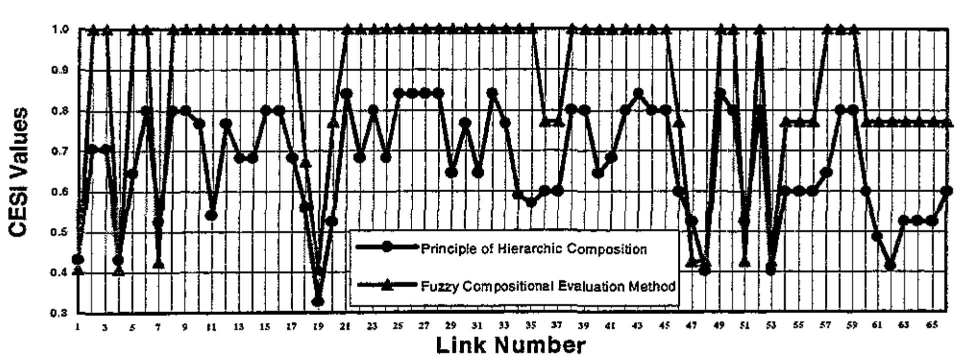

Figure 6: Comparisons of the estimated CESI values using the typical AHP and the fuzzy compositional AHP

Conclusion

This paper indicates some aspects of multicriteria evaluation capability of AHP in the context of the multicriteria environmental sensitivity evaluation, and illustrates the application of the method to the central Geelong road network. The AHP can effectively transfer and aggregate different perspective of several experts, deal with multiple criteria for both tangible and intangible and interestingly measure the consistency of the respondents' judgements. The hierarchy structure helps to systematically decompose the complex problems down to several smaller interrelated decision elements. The pairwise comparison approach is used to uncover the relative importance among these elements. The principle of hierarchic composition and the fuzzy compositional evaluation methods were applied to synthesise all local priorities to derive global priorities (the CESI values) of all road links. It is found that the typical AHP expresses more powerful capability in differentiating links according to their combined ES characteristics than the fuzzy compositional AHP. However, the latter can be used as a conservative decision making tool when considering the composite ES nature of road links and the most critical environmental criterion. In addition, both approaches in combination with the ESM concept can be utilised to identify environmental problem locations at local level and specify the likely causes of these problems. This is of particular importance in understanding environmental problems in urban road networks, establishing suitable functional road hierarchy classification, prioritising the special investigation for links having environmental problems, and allocating limited budget for traffic calming implementation.

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